LADEE SEARCH FOR A DUST EXOSPHERE: A HISTORICAL PERSPECTIVE. D. A. Glenar[1,2], T. J. Stubbs[3,2], and R. Elphic[4,2], [1]Univ. of Maryland, Balt. Co. (dglenar@umbc.edu), [2]NASA Lunar Science Institute, [3]NASA Goddard Space Flight Center, [4]NASA Ames Research Center.

Introduction: The LADEE search for exospheric dust is strongly motivated by putative detections of forward-scattered sunlight from exospheric dust grains which were observed during the Apollo era. This dust population, if it exists, has been associated with charging and transport of dust near the terminators [1], [2]. It is likely that the concentration of these dust grains is governed by a saltation mechanism originated by micrometeoroid impacts, which are the source of the more tenuous ejecta cloud [3].

Strong excess brightness at the limb was detected in Apollo 15 coronal photography from within shadow just before orbital sunrise, and interpreted as scattering by "tenth micron" dust grains extending many kilometers above the surface. The observed brightness was equivalent to near-surface dust concentrations as large as ~0.10 cm^{-3} and dust scale heights of 5-10 km [3], [4]. Further evidence of a substantial dust exosphere came from visual observations by Apollo 17 astronauts of lunar horizon glow (LHG) in the minutes before orbital sunrise [5], and in addition to this, radially-oriented crepuscular rays dubbed "streamers" [6] that brightened dramatically in the last seconds before sunrise. The latter could only be produced by a scattering medium that extends to very high altitudes. Although sodium emission was proposed as this high altitude scattering source, its intensity is far too small to explain the visual observations [7]. Detectable sky brightness was also recorded by uplooking photometers on the Lunokhod-2 lander shortly after surface sunset, and attributed to an overlying dust layer [8]. Any of the dust distributions inferred by these observations would be quickly detectable by the LADEE Ultraviolet Spectrometer (UVS) in either scattering or absorption mode, and also by the Lunar Dust Experiment (LDEX), as an excess of discrete dust grain impacts superimposed on a recognizable background current from smaller unresolved grains.

In sharp contrast to these Apollo-era predictions, more recent optical searches [9] [10] (still prior to the LADEE mission) have failed to detect LHG. As described below, these studies result in upper-limits for dust abundance that are several orders of magnitude smaller than the earlier predictions. This raises new questions about the interpretation of the early observations, including calibration errors, the influence of stray light from bright out-of-field sources, and possible misinterpretation of phenomena seen during the visual observations.

Clementine Star Tracker Search: Portions of 25 orbits were allocated to searches for LHG using the Clementine navigational star trackers, with the Moon occulting the Sun. Out of this data set, four of these image sequences were made at small solar elongation angles and were partially or totally free of Earthshine at the limb, which lessens the chance of stray light contamination. Solar streamer structure appeared in many of these images after subtraction of a zodiacal light model. However, no convincing evidence of a dust exosphere appeared in the brightness difference images, down to a detection limit of a few x 10^{-13} B_{Sun} (with B_{Sun} the mean solar disk brightness). For grains of radius 0.10 μm, this limit corresponds to a dust abundance of a few hundred grains cm^{-2} or less along a tangential line-of sight [9]. Estimates of dust concentration are highly sensitive to grain size.

Dust Upper-Limits from LRO LAMP: LRO/LAMP completed a number of observations from within lunar shadow to search for forward scattering of sunlight at the sunrise or sunset limb. Far-UV measurements are especially sensitive to scattering by small (0.1-0.2 μm radius) dust grains since the scattering efficiency is near maximum for that combination of grain size and wavelength. No definitive detection of dust has yet been made by LAMP, although weak excess brightness was observed in several observations after correcting for grating scattered light. Using the rationale that the net-brightness results could be masking a still-weaker dust signal, the excess brightness signals were equated with scattering from 1D exponential models which define dust upper limits, with surface concentration n_0~10^{-5} cm^{-3} and H= 5-10 km [10]. Additional, coordinated LAMP-LADEE observations with LADEE are being carried out in order to refine these estimates.

Figure 1 summarizes these dust estimates and observational upper limits for a tangential limb viewing geometry. Brightness measurements have been converted to line-of-sight (LOS) concentration using Mie scattering theory and a broadband model for lunar dust optical constants [11], assuming a narrow size distribution of dust grains, with r_{peak}= 0.10 μm. Tangent height is 5-10 km, but that is not tightly constrained in this comparison. The uplooking Lunokhod measurements are converted to limb viewing geometry using a dust distribution model with scale height of 5 km. The

Clementine and LRO measurements correspond to LOS concentrations of no more than a few hundred grains cm^{-2}.

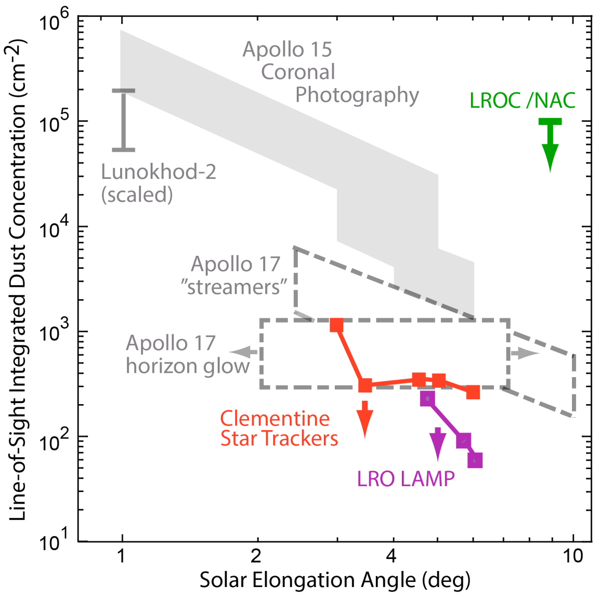

Figure 1. Summary of putative dust measurements and upper limit estimates prior to the LADEE mission.

Implications for the LADEE Dust Search

It is useful to express these upper limit estimates in terms of the predicted response of the LADEE dust detection instruments. Such estimates can serve as [very] rough benchmarks for comparison with measurements that are now underway, or will soon be carried out.

The UVS [12] consists of a limb telescope and spectrometer which measures the dust scattered light spectrum between ~230- 830 nm, and a separate solar occultation telescope which makes spectrally resolved measurements of dust in absorption over the same range of wavelengths. For 0.10 µm radius grains at 1 AU, Mie computations show that the per-grain radiance at near-UV/VIS wavelengths is 0.4-0.6 R nm^{-1}, where 1R= $(1.0 \times 10^6/ 4\pi)$ ph s^{-1} cm^{-2} sr^{-1}. For an LOS concentration N_{LOS} of ~300 illuminated grains cm^{-2} (a reasonable upper-limit estimate from Figure 1) one therefore expects to observe a dust scattering intensity of 40-60 R or less at the limb. A similar line of reasoning can be applied to UVS solar occultation measurements [13]. The extinction efficiency (Q_{ext}) for Mie grains lies between 1 and 2 for this size and wavelength. This corresponds to an LOS optical depth τ (defined by $\pi * r_{grain}{}^2 * Q_{ext} * N_{LOS}$) of ~ 2×10^{-7}, i.e. the attenuated fraction of the solar signal. A value several times larger (perhaps $\tau \sim 10^{-6}$) is entirely reasonable, due to the ability of the occultation channel to probe the exosphere all the way to the surface.

It is also interesting to examine whether such small dust concentrations near the terminators could produce a detectable integrated signal current for the LDEX instrument [14] at an altitude of several x 10 km above the terminator. For a hypothetical dust exosphere consisting of 0.10 µm grains, surface concentration $n_0 = 10^{-5}$ cm^{-3} and scale height H= 5 km, the dust grain concentration will be ~2.5×10^{-8} cm^{-3} at an altitude of 30 km (a representative altitude). Results of the LDEX calibration show an effective instrument collecting area of ~ 100 cm^{-2}, and charge per mass (Q/m) of ~ 2 C kg^{-1} for grains impacting at the orbital velocity of ~ 1.7 km s^{-1}. Given the volumn swept out by the LDEX aperture (~2×10^7 cm^3 s^{-1}), the resulting impact rate will therefore be ~ 0.5 grains s^{-1}. Assuming a dust mass density of 3 gm cm^{-3}, this adds a contribution of ~80 e^- s^{-1} to the collective current signal, a value which is far smaller than the typical collective current measured by LDEX [15] and thus not detectable by that instrument.

In general the detection of a small-grain dust population consistent with the low Clementine and LAMP upper limit estimates will be a challenge for the LADEE mission. On the other hand, these prior measurements represent only a small part of the LADEE search space, and none coincide with the occurance of major meteor streams. The LADEE dust search is sure to produce surprises.

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